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Description and Field Evaluation of the Broad-Band Underwater Recording Buoy System

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Defence R&D Canada – Atlantic

Technical Memorandum

DRDC Atlantic TM 2005-231

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Abstract

This report documents the design and features of a new, four-element broad-band underwater recording buoy system. These buoys, named the Broad-band Underwater Recording Buoys (BURB), were built to facilitate medium-frequency underwater acoustic transmission experiments and for measurement of moving vessel acoustic signatures. Each BURB supports two wide-band hydrophones, digitized with 16-bit resolution at 40,000 samples per second each, and recorded onto internal hard-drive. Each BURB records its differential GPS position at 1 s intervals. Total operational duration is in excess of 36 hours of continuous operation. In an alternate configuration, each BURB can acquire four-channel data from a new 3-axis acoustic intensity sensor. This report presents details on the BURB design, construction, acoustic calibration, and operation. Example results from acceptance sea-trials conducted in March and April 2005 are presented.

Résumé

Le présent rapport documente la conception et les caractéristiques d’un nouveau système de bouées d’enregistrement sous-marin large bande à quatre éléments. Ces bouées, appelées « bouées d’enregistrement sous-marin large bande » (Broad-band Underwater Recording Buoys – BURB), ont été construites pour faciliter les expériences de transmission acoustique sous-marine et la mesure des signatures acoustiques de navires en mouvement. Chaque BURB est associée à deux hydrophones large bande dont les signaux sont numérisés à une résolution de 16 bits avec 40 000 échantillons par seconde et sont enregistrés sur un disque dur interne. Chaque BURB enregistre sa position GPS différentielle à des intervalles de 1 s. La durée totale d’exploitation continue dépasse les 36 heures. Dans une autre configuration, chaque BURB peut acquérir des données sur quatre canaux transmises par un nouveau capteur d’intensité acoustique trois axes. Nous présentons ici des détails touchant la conception, la construction, l’étalonnage acoustique et le fonctionnement des BURB ainsi que des exemples de résultats des épreuves de fonctionnement en mer menées en mars et avril 2005.

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Executive summary

Introduction

There has been a long-standing need for a self-contained, broad-band, calibrated underwater acoustic recording system. The primary interest lies in the measurement of moving vessel or torpedo underwater acoustic signatures. Knowledge of these underwater acoustic signatures allows a more accurate understanding of ship vulnerabilities and improved defence against submarines, torpedoes, or other underwater weapons. Additionally, such systems could find use in acoustic propagation and ambient noise studies. A collaborative development project was initiated in mid-2004 between DRDC Atlantic and the Institute of Ocean Sciences (DFO) for the development of a set of four portable, internally-recording hydrophone buoys equipped with high-resolution GPS, dubbed the Broadband Underwater Recording Buoy (BURB) system. Initial testing of the BURB system took place in March and April 2005 at the Institute of Ocean Sciences, near Sidney, B.C.

Results

This report documents the design and features of the BURBs. In the standard configuration, each BURB supports two wide-band hydrophones, digitized with 20 kHz bandwidth and 16-bit resolution, recorded continuously onto internal hard-drive. In an alternate configuration, each BURB can record four-channel data from a new 3-axis acoustic intensity sensor. Differential GPS position is recorded at 1 s intervals. Total operational duration is in excess of 36 hours of continuous operation, limited by batteries. System performance in measurement of moving vessel signatures and acoustic transmission experiments was verified.

Significance of the Results

A new, portable, broad-band underwater acoustic recording capability has been created. With some improvements, the BURBs could possibly serve as a forward acoustic ranging system.

Future plans

It is intended that underwater acoustic signature measurements on several CF ships conducting high-speed manoeuvres will be performed within the next year. An at-sea evaluation of pulse reception using the directional acoustic intensity sensors is planned for late 2005.

Trevorrow, M., Vagle, S., and Hall-Patch, N., 2006. Description and field evaluation of a broad-band underwater recording buoy system. DRDC Atlantic TM 2005-231. Defence R&D Canada – Atlantic.

Sommaire

Introduction

Le besoin d’un système d’enregistrement acoustique sous-marin large bande étalonné et autonome existe depuis longtemps. Le principal intérêt d’un tel système tient à sa capacité de mesurer les signatures acoustiques sous-marines de navires ou torpilles en mouvement. La connaissance de ces signatures acoustiques sous-marines permet de comprendre plus exactement les vulnérabilités des navires et d’améliorer la défense contre les sous-marins, les torpilles et autres armes sous-marines. En outre, ces systèmes pourraient être mis à profit dans le cadre d’études sur la propagation acoustique et le bruit ambiant. Un projet de collaboration associant RDDC Atlantique et l’Institut des sciences de la mer (MPO) a été lancé au milieu de l’année 2004 en vue du développement d’un ensemble de quatre bouées hydrophoniques transportables d’enregistrement interne avec GPS haute résolution. Les premiers essais de ce système de bouées, appelées « bouées d’enregistrement sous-marin large bande » (Broadband Underwater Recording Buoy - BURB), ont eu lieu en mars et en avril 2005 à l’Institut des sciences de la mer, près de Sidney (C.-B.).

Résultats

Le présent rapport documente la conception et les caractéristiques des BURB. Dans la configuration ordinaire, chaque BURB est associée à deux hydrophones large bande dont les signaux numérisés sont transmis dans une largeur de bande de 20 kHz avec une résolution de 16 bits et enregistrés sur un disque dur interne. Dans une autre configuration, chaque BURB peut acquérir des données sur quatre canaux transmises par un nouveau capteur d’intensité acoustique trois axes. La position GPS différentielle est enregistrée à des intervalles de 1 s. La durée totale d’exploitation continue dépasse les 36 heures, la durée maximale dépendant des batteries. On a vérifié les performances du système en ce qui concerne la mesure des signatures de navires en mouvement et les expériences de transmission acoustique.

Importance des résultats

Une nouvelle capacité d’enregistrement acoustique sous-marin large bande a été produite. Avec quelques améliorations, les BURB pourraient éventuellement être utilisées en tant que système de télémétrie acoustique aval.

Recherches futures

D’ici un an, on compte effectuer des mesures de la signature acoustique sous-marine de plusieurs navires des FC lors de manoeuvres à grande vitesse. Une évaluation en mer de la réception d’impulsions au moyen des capteurs directionnels d’intensité acoustique est prévue pour la fin de 2005.

Trevorrow, M., Vagle, S., et Hall-Patch, N., 2006. Description and field evaluation of a broad-band underwater recording buoy system [Description et évaluation en conditions réelles d’un système de bouées d’enregistrement sous-marin large bande]. DRDC Atlantic TM 2005-231. Defence R&D Canada – Atlantic.

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Acknowledgements

This collaborative instrumentation development was supported by the Canadian Dept. of National Defence Technology Investment Fund and other Defence R&D Canada - Atlantic project funds. The Institute of Ocean Sciences provided laboratory and boat facilities in support of the field evaluations, and arranged for use of the *CCGS Vector* during the mid-April 2005 field trials. The field trials were ably assisted by Rob Reed, Scott Rose, Ron Teichrob, Joshua Abanto, Phillipe Benoit, and Robin Prussin, all of the Institute of Ocean Sciences. Dr. E. Carmack of IOS provided the use of his personal vessel *Wicklow* for some of the trials in March 2005.

1. Introduction

For a variety of applications at DRDC Atlantic there has been a long-standing need for a self-contained, broad-band underwater acoustic recording system. The primary naval interest lies in the measurement of ship or torpedo underwater acoustic signatures, and in particular those of manoeuvring ships and torpedoes. Knowledge of these underwater acoustic signatures allows a more accurate understanding of ship vulnerabilities and improved defence against submarines, torpedoes, or other underwater weapons. Additionally, it is anticipated that such a system could be used for quantitative studies of natural and anthropogenic noise sources, marine mammal monitoring, acoustic propagation and scattering effects, and as test platforms for sonobuoy research. A collaborative development project was initiated in mid-2004 between DRDC Atlantic and the Institute of Ocean Sciences (DFO) for the development of a set of four portable, internally-recording hydrophone buoys equipped with high-resolution GPS. This system has been dubbed the Broadband Underwater Recording Buoy system (BURBs). Initial testing of the BURBs system took place in March 2005 at the Institute of Ocean Sciences, followed by a dedicated sea-trial with the *CCGS Vector* during mid-April 2005. This report documents the design and features of the BURBs, and gives a preliminary evaluation of system performance based on data from the two sea-trials at IOS.

The intent of this development was not to replace dedicated underwater acoustic ranges, as the acoustic signature of CF vessels while stationary or at low speeds is adequately measured by DND acoustic facilities on both coasts. However these ranges are generally too confined (i.e. in shallow water close to shore) to allow safe vessel manoeuvres at meaningful speed, and thus high-quality data on manoeuvring vessels has been lacking. For the same reason, recent attempts to measure moving-ship signatures from convenient fixed platforms have been largely unfruitful. As an example, an attempt was made in early 2003 to measure the acoustic signature of the *HMCS Ville de Quebec* in Bedford Basin, Nova Scotia. These measurements were severely compromised by the fact that the ship was not able to manoeuvre closer than approximately 2 km from the DRDC Atlantic acoustic barge. A better approach would have been to deploy several small recording buoys near the center of the basin, allowing the ship to manoeuvre freely in close proximity to the recorders. In future, it is conceivable that BURBs could be shipped and deployed almost anywhere in the world, taking advantage of opportunities during vessel or weapon trials. This buoy system could potentially provide a forward-ranging capability for CF ships.

Each BURB is designed to record continuously 2-channels with up to 22-kHz bandwidth per channel with 16-bit (92 dB) resolution. The digital data is stored in binary file format similar to the industry-standard WAV format. High resolution differential GPS position data is recorded at 1 s intervals. Battery duration is currently in excess of 36 hours. In their standard configuration, each buoy has two broad-band hydrophones that can be suspended at depths up to 32 m. The intended usage is to have 3 or 4 buoys deployed in a test area, both to provide a large spatial coverage and to provide measurement redundancy. The buoys are designed to be small enough to be deployed by hand from a RHIB or similar small launch. Additionally, each buoy can be re-configured to handle data from a 4-channel acoustic intensity sensor (e.g. Wilcoxon TV-001). Precise time-referencing of the recorded data is accomplished through recording the pulse-per-second (PPS) trigger from the differential GPS system.

As compared to conventional sonobuoys, BURBs offer a calibrated acoustic measurement, greater dynamic-range, larger acoustic bandwidth, lower self-noise (no RF interference), longer operational duration, and have a high-resolution positional measurement. Having digitally-recorded data compatible with an industry standard formats saves the additional data translation step required with analog recordings, and allows the use of commercially available software for playback and analysis. With adjustable hydrophone depths, the units can be adjusted to suit local conditions. Additionally, the hydrophone calibrations can be easily measured and maintained using DRDC Atlantic acoustic calibration facilities. Note that maintaining calibration is a serious problem for permanently installed underwater sound ranges.

The Instrumentation Development group at the Institute of Ocean Sciences (Dept. of Fisheries & Oceans) in Sidney, B.C. has been developing and using self-contained hydrophone recording systems for more than 15 years. These systems have been used for a variety of measurements, such as sea-surface noise, under-ice ambient noise, acoustic noise pollution at aqua-culture sites, and UW noise studies on BC Ferries. Recently IOS has developed and deployed several moored systems for long-term monitoring of marine mammal (e.g. Orca) vocalizations in B.C. coastal waters (Vagle et al., 2004). Those moored systems recorded one hydrophone channel with 16-bit digitization at either 1 or 20 kHz, streaming the data onto hard-drives. This present collaboration saw the capability of the existing IOS systems expanded to provide greater bandwidth, greater number of channels, provision of a high-resolution GPS position measurement, and precise time-synchronization. An additional benefit to this collaboration was continued support of underwater acoustic instrumentation development at both IOS and DRDC Atlantic. This enhances the capability within both labs for environmental acoustics and marine mammal monitoring.

2. Instrument Description

This section describes the mechanical and electronic construction of the BURB system, along with results from internal noise and calibration tests.

2.1 Overview and Physical Description

The BURB system is composed of a set of four, identical buoys, each complete with the necessary hydrophones, cables, connectors, batteries, and GPS receivers. Each buoy is completely self-contained, running on a rechargeable battery which is capable of providing at least 36 hours of continuous operation. Each BURB is equipped with a 12-channel WAAS GPS receiver, providing position and time synchronization data at 1-second intervals. In the standard configuration implemented in March and April 2005, each buoy supported two independent hydrophone channels, each digitized at 40,000 samples per second with 16-bit resolution. The recorded data files are similar to audio WAV files, with data from the two hydrophones contained in the left and right audio channels. Alternately, the buoys can be re-configured to record four channels from a single acoustic intensity sensor (e.g. Wilcoxon TV-001) at 20,000 samples per second per channel (i.e. same total sampling bandwidth).

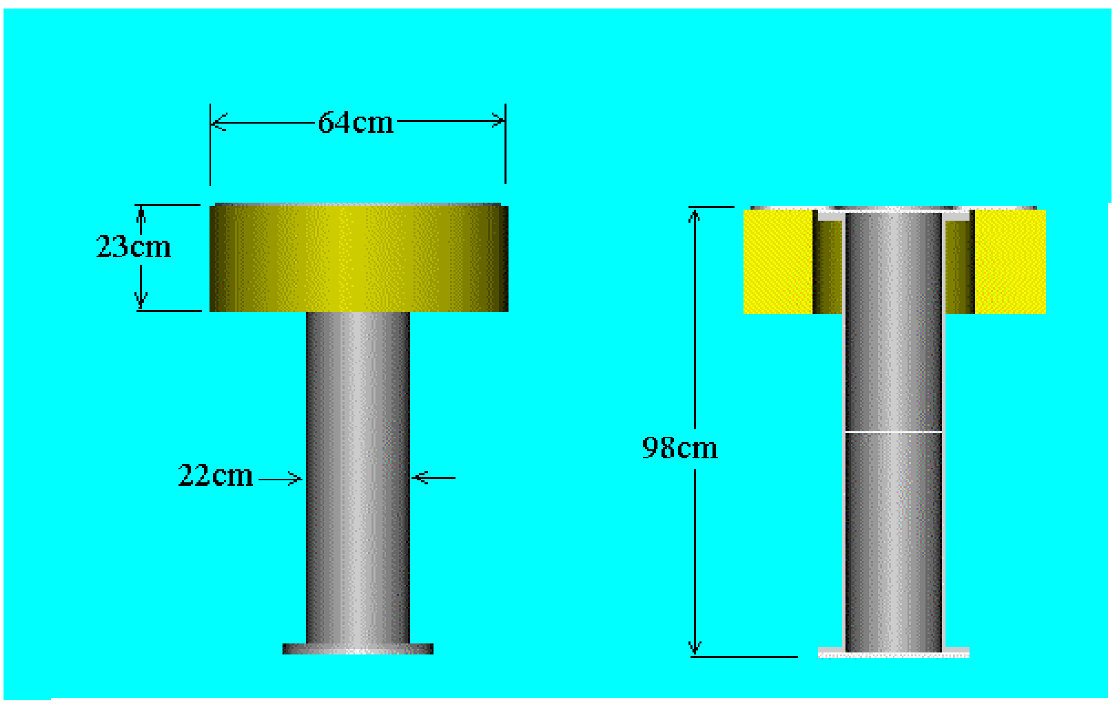

Figure 2-1 dimensioned mechanical drawing of a BURB.

Mechanically, each buoy is constructed around a watertight, eight-inch (20.3 cm) inside diameter by 92 cm long pressure housing, as shown in Figure 2-1. The pressure case is constructed of 6061TI aluminum alloy, and is designed to withstand immersion to depths up to 30 m. The pressure case is divided into two compartments, with the lower for batteries and the upper containing electronics. Four 12 Amp·hr, 12 VDC absorbed-glass-mat batteries are provided, wired in parallel. Sealing flanges (33-cm outer diameter) are provided at each end of the pressure case. Each compartment is sealed with a 1.3 cm thick end cap, with a double O-ring face seal. A 20-cm high by 61-cm diameter closed-cell foam floatation collar is attached around the top of the buoy. The total weight of each buoy (in air) is 47 kg. The floatation collar is painted a bright yellow colour to enhance buoy visibility. The total length of each buoy, including the top connectors and cables, is approximately 117 cm. In deployments after July 2005 the BURBs where fitted with a removable lifting and antenna frame extending approximately 40 cm above the top plate.

Each buoy has three waterproof connectors on top end-cap, as shown in Figure 2-2. These connectors are: (1) an XSK-12 BCL (12 pins) for battery charging, PC reset, and Ethernet communications, (2) a BH10F (10 pins) for the hydrophone cable, and (3) a MCBH6-FS (6 pins) for the DGPS antenna. A mating Ethernet and battery-charging interface box is provided for each buoy. The DGPS antenna and receiver unit (Garmin model GPS18LVC 12-channel receiver) is mounted inside a 8.9-cm diameter epoxy disc, with a flashing white LED on the side to indicate internal activity. The DGPS receiver is programmed to deliver a standard NMEA $GPRMC message (see Appendix 2) at 1 Hz, and also provides a pulse-per-second trigger pulse. With Wide-Area Augmentation System (WAAS) differential corrections the manufacturer quotes a positional accuracy of < 3 m (rms). The satellite-based pulse-per-second trigger is synchronized to UTC to better than 1 μs. In normal use the pressure case need not be opened to access the internal computer and/or recharge the batteries. Connection to the internal computer for configuration and data download is provided through industry-standard VNC protocols. External on/off commands can be given by passing a small magnet over two magnetic switches mounted on the underside of the top end-cap. An external PC reset switch is provided on the interface box. BURB operating instructions are summarized in Appendix 4.

Figure 2-2 photo of assembled buoy, showing the top end-cap (black), the three underwater connectors, interface cable and box (left), GPS receiver (orange disk – right), floatation collar (yellow), and cables with one hydrophone (middle front).

In the standard configuration, each BURB supports two Burns Electronics model CR-100 hydrophones. These hydrophones are horizontally omni-directional, with an integral 20 dB pre-amplifier, yielding a nominal sensitivity of -186 dB re 1V/μPa. The manufacturer's specification for these hydrophones quoted a linear frequency range from 7 Hz to 100 kHz (to -3 dB), and a depth rating of at least 400 m. The main receiver electronics were designed around an expected maximum broadband sound pressure level (SPL) of approximately 185 dB re μPa. The minimum detectable SPL, given by the internal noise levels and maximum gains (described in section 2.3 below), is approximately 104 dB re μPa. Each hydrophone has a 32 m long, 3-conductor cable, joined through a y-splice onto a 1.5 m long, 8-conductor cable which connects directly onto the top end-cap. Thus, either hydrophone may be deployed up to 32 m below (or away from) the buoy. A custom-built hydrophone motion-damping suspension, similar to those provided on standard sonobuoys, is intended to be attached along each hydrophone cable approximately 5 m above the hydrophones (these were not installed during the March and April 2005 trials).

Figure 2-3 photo of a deployed BURB, taken 12 April, 2005 in Patricia Bay, B.C.

When deployed, each BURB floats with the majority of the floatation collar exposed, as shown in Figure 2-3. The weight of the batteries in the bottom compartment provides a strong righting-moment. Two 6.4-cm diameter mounting tubes are provided for attaching recovery aids such as Xenon strobe lights, radio-direction-finding beacons, or radar-reflectors. Because of the inclusion of a standard PC hard-drive, BURBs should not be operated at temperatures below approximately 2°C.

2.2 Description of Electronics and Software

A block diagram of the internal electronics is shown in Figure 2-4, with photos of the internal electronics shown in Figure 2-5. The heart of each buoy is a single-board PC (Diamond Systems Inc. model Hercules EBX, using a Pentium III class 550-MHz processor, running a Windows 2000 operating system). A custom C++ program for data acquisition and filehandling was created. This single-board PC is 14.6 cm wide by 20.3 cm long, with a maximum power requirement of 12 W. Communication with an external computer (or network) is provided through a 100baseT Ethernet port, wired directly to a connector on the top end-cap. Additionally, the Hercules EBX board provides an integral 32-channel A/D converter, four serial com-ports, four USB ports, and 50 digital I/O pins. At present the system can only operate continuously. The acoustic data is directly recorded on a 80-Gbyte hard-drive, allowing a total recording capacity of roughly 128 hours. The binary data file format is similar to WAV format, but with additional headers for GPS position and amplifier gain settings (see Appendix 1 for a complete format specification). The resulting data files can be read with commercially-available audio data display and analysis software. The data acquisition process is appropriately buffered so that there is no signal loss between data records (nominally 1 s in length). The GPS pulse-per-second synchronization signal is contained in the least-significant data bit of the two data channels, i.e. the LSB is zero (even numbers) except in the data sample corresponding to the PPS trigger. The PPS trigger pulse is 20 ms (800 samples) in length, with its leading edge aligned to the change in seconds.

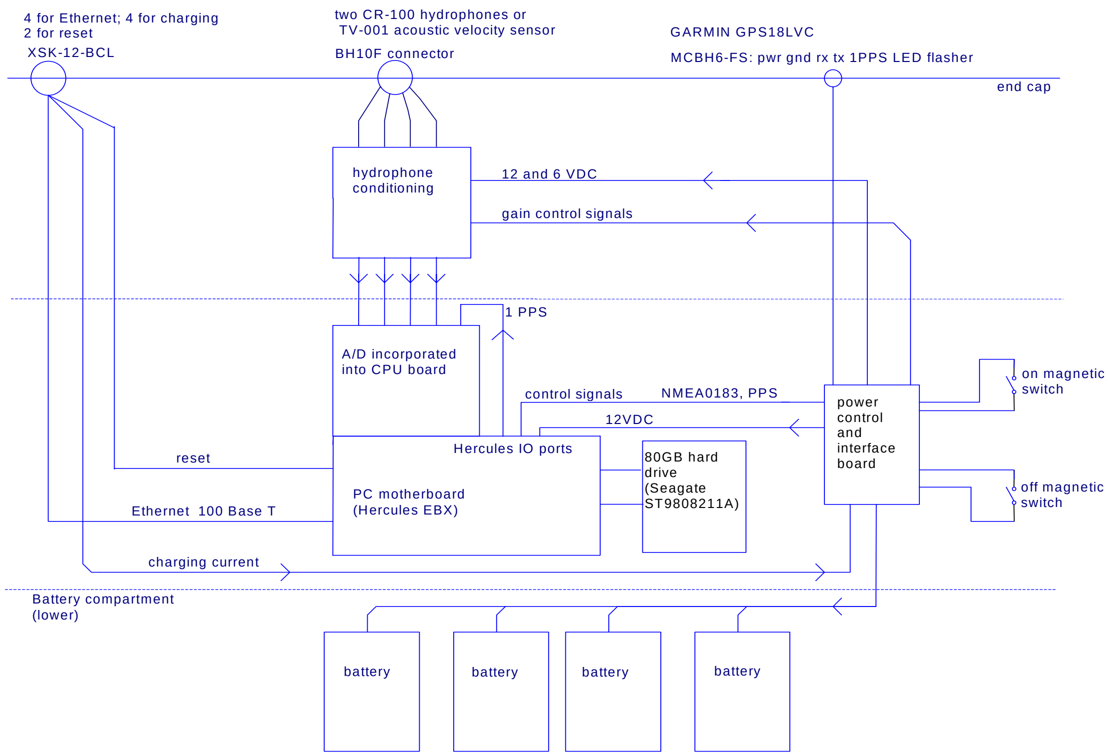

Figure 2-4 Electronic block diagram of the BURB system.

Each buoy has two custom-designed printed-circuit cards for (i) hydrophone signal conditioning and (ii) power control. The hydrophone interface card provides band-pass filtering, a pre-digitization gain (up to 84 dB), and delivers pre-amplifier power (6.8 VDC, 20 mA) for either the hydrophones or 4-channel acoustic intensity sensor. A programmable 8-pole elliptic RC-filter integrated-circuit provides low-pass anti-aliasing with a -3 dB corner frequency of 21.5 kHz. The high-pass -3 dB corner frequency is 7.5 Hz. Overall gain control is implemented in software, through control lines from the PC motherboard through the power-interface card to the hydrophone conditioning card. To extend the dynamic range of the system it is equipped with a software implemented Automatic Gain Control (AGC) algorithm which dynamically varies the system gain. The AGC values are updated for each data record, nominally 1 s duration, and the values for each channel are recorded within each data record header.

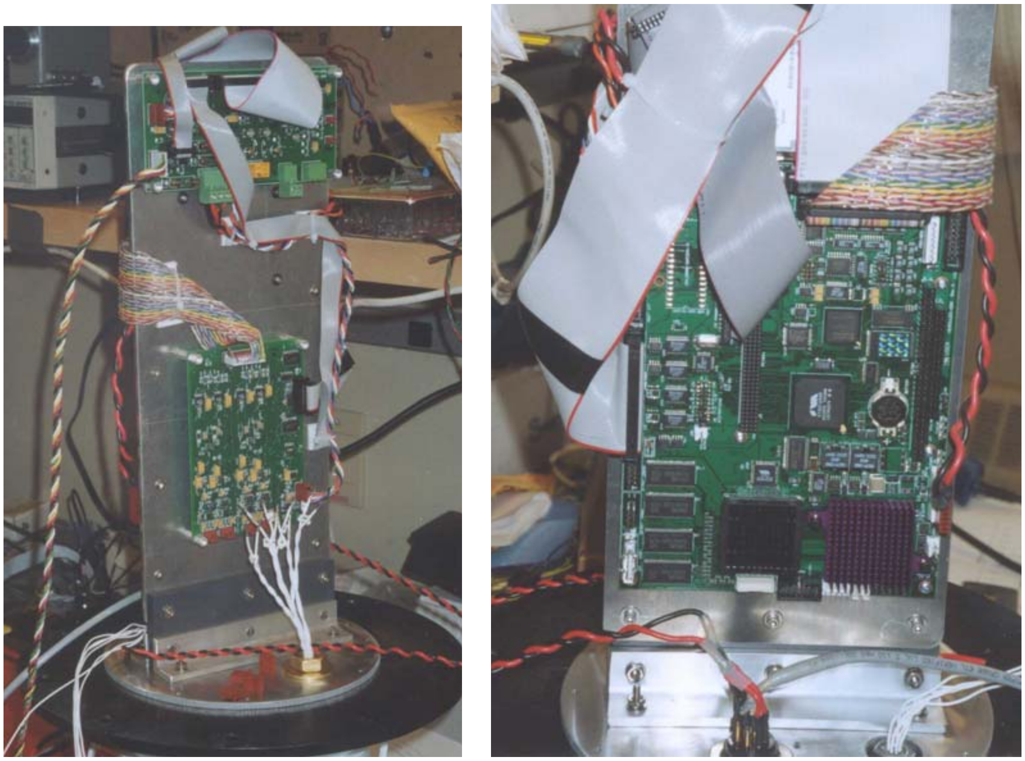

Figure 2-5 photograph of BURBs internal electronics, showing hydrophone receiver card (left lower), power distribution card (left upper), and single-board PC (right). A single 80GB hard-drive is hidden behind gray ribbon-cables in upper right.

The concept behind the AGC is quite simple. For most applications, the gain should be set to produce the largest possible signal that avoids overload of the A/D converters. However, the capability for rapid gain reduction is needed to handle sudden increases in the input signal strength. On the other hand, we require a slow to moderate gain increase to improve signal to noise ratio when the signal becomes faint. For intermittent signals like passing ships or acoustic pulses it is important to prevent the gain from rising too high during periods with lower acoustic noise levels. The BURB AGC operates as follows:

First, calculate a low-pass filtered estimate of any DC offset in the data (normally quite small) using

$$DC = A * DC + (1 - A) * input;$$

where A is a low-pass filtering constant (nominally = 0.95), DC is the mean offset which is initialized to 0 upon start of data logging, and *input* represents the 16-bit data values for a given hydrophone.

Secondly, subtract this DC offset from the input data, i.e.

hp_out = *input* - *DC*;

where now *hp_out* is the de-trended input signal.

Thirdly, rectify this signal, i.e.

rect_input = abs(*hp_out*);

then compare each input value against the mean envelope of the input signal (*envelope*). If *rect_input* > *envelope* then attack (decrease gain) the mean signal, otherwise decay (increase gain). This can be expressed with an *if-else* statement,

```
if (rect_input > envelope){
  envelope = envelope+ (rect_input - envelope) * AGC_Filter_attack;
}else {
  envelope = envelope* AGC_Filter_decay;
}
```

where *envelope* keeps track of the mean signal strength and is initialized to zero at startup, *AGC_Filter_attack* is a user specified parameter which determines how fast the algorithm will respond to an increased input signal strength, and *AGC_Filter_decay* is a user specified parameter which determines how fast the algorithm will respond to a decreasing input signal strength. Default values for these two coefficients are 0.05 and 0.999, respectively, as shown for example in the BURB configuration file Figure A4-1.

Finally, compare the modified mean level (envelope) against a user specified acceptable threshold level *AGC_Level_to_aim_for*, which can have values between 0 and 32768 (16 bits), to determine the level of system gain to use in the next data record. If the product of mean level and current gain value is less than this threshold then increase the system gain, otherwise decrease the gain. The total *gain* in each channel is composed of a combination of two gain stages, with total range from 1 to 800 times in 80 discrete steps. The procedure above is repeated for each of the two (or four channels depending on operating mode) in the BURB for each data record (nominally 1 s long). Note that the *AGC_Level_to_aim_for* is an estimate of the mean signal level, and since most underwater acoustic processes have a broad distribution of amplitudes, then the desired mean level must be significantly lower than the maximum allowable input signal (32768 counts) to avoid clipping the peaks. For normal oceanic ambient noise a *AGC_Level_to_aim_for* near 4000 counts is recommended. For reception of intermittent acoustic pulses, an even lower threshold value (near 1000 counts) is recommended, depending on the pulse duration and duty cycle.

2.3 Calibration and Internal Noise Tests

An important feature of the BURBs is the acoustic calibration, whereby the raw A/D counts (16-bit signed integers, up to ±32768) are converted to the standard underwater acoustics unit of microPascals (μPa). The basic approach followed here is to directly compare the BURBs output to that from a calibrated reference hydrophone at a number of discrete frequencies between 0.5 and 20 kHz (lower frequency limited by the response of the transmitter). This calibration was performed at the DRDC Atlantic Acoustic Calibration Barge (ACB) in Bedford Basin, N.S. on two occasions in August and November 2005. The hydrophones (reference plus one or two BURB) were suspended roughly 10 cm apart, each with an unobstructed path to the source. The reference hydrophone (a Bruel & Kjaer model 8106) was calibrated by the manufacturer, having a flat pass-band from 10 Hz to 100 kHz. The output root-mean-square voltage of the reference hydrophone was sampled with ACB calibration systems. A calibrated J-9 acoustic projector, located approximately 4 m from the hydrophones, was used to generate single-frequency tones for the comparisons. Tones from 0.5 to 20.0 kHz, increasing in steps of 100 Hz, were transmitted. Typical SPL at the reference hydrophone was 132 dB re μPa.

Figure 2-6 shows the result of this calibration process for the two hydrophones of BURB 1. This calibration was conducted on the bare hydrophone-cable assembly, without the BURB electronics attached. The hydrophone response is dominated by a strong resonance feature at 6 to 10 kHz, contrary to the initial expectation of nominally flat response across this frequency range. The variation from maximum to minimum is approximately 30 dB, with a peak sensitivity near 6 kHz roughly 10 dB above the design sensitivity. This creates a situation where the AGC levels will be strongly affected by signals in the 5 to 6.5 kHz band, with overall low signal to noise properties in the 7 to 10 kHz band. Note that the sensitivity is reasonably well-behaved below 4 kHz, a region which generally dominates underwater ambient and vessel noise signatures. Above 10 kHz the hydrophone response shows a general rise towards the design point (-185 dB) with some smaller resonant peaks and troughs.

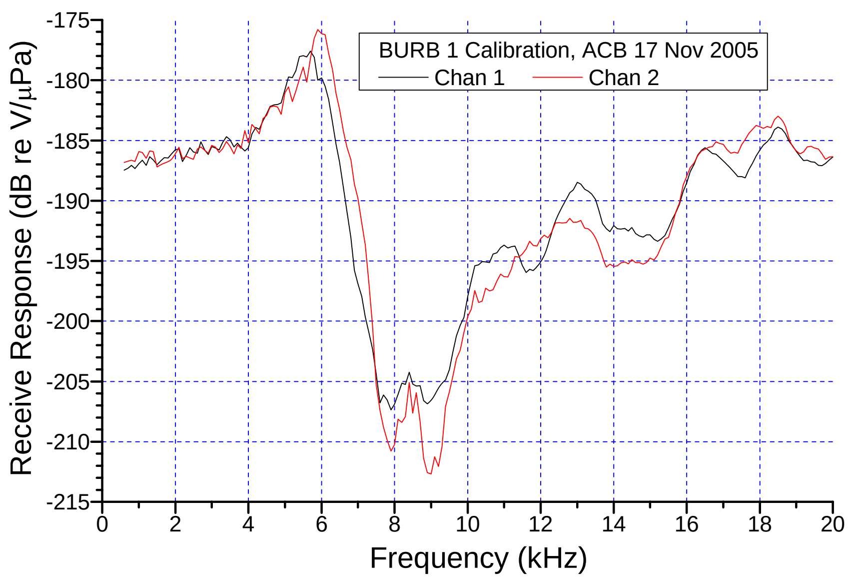

Figure 2-6 Calibration results for the two hydrophones of BURB 1, taken 17Nov. 2005 using facilities at the DRDC Atlantic acoustic calibration barge.

An earlier calibration using the same facilities, but recording the calibration tones with the BURB electronics, showed qualitatively similar behaviour below 6 kHz (differences at higher frequencies were attributed to improper calibration technique). This result was useful in two respects: (i) it showed that the hydrophone receiver circuitry did not create additional frequency response artifacts, and (ii) allowed calculation of an overall BURB calibration factor in μPa per count. This overall calibration factor for each hydrophone was computed by matching the BURB output at 1 kHz, corrected for any internal AGC values, to the hydrophone calibrations. Then the frequency dependence is specified with a normalized version of the bare hydrophone calibration (e.g. Fig. 2-6). Individual hydrophone response factors are presented in Appendix 3.

Using the typical low-frequency conversion factor for the BURBs (+106 μPa/count, valid for frequencies < 4 kHz), a SPL clipping threshold of 196 dB re μPa can be calculated. Clearly, this maximum signal would occur with the AGC at minimum internal gain (G1 = 1.0, G2 = 1.0); at higher gains the clipping threshold would be lower. Clearly, this value is sufficiently high to measure adequately the radiated noise from large vessels, which can have source levels up to 190 dB (re μPa at 1 m) but are generally 10's to 100's of meters away. Note that some impulsive acoustic sources (e.g. underwater detonations or pile driving) or active sonar transmissions can exceed this maximum sound pressure level, even at great distances.

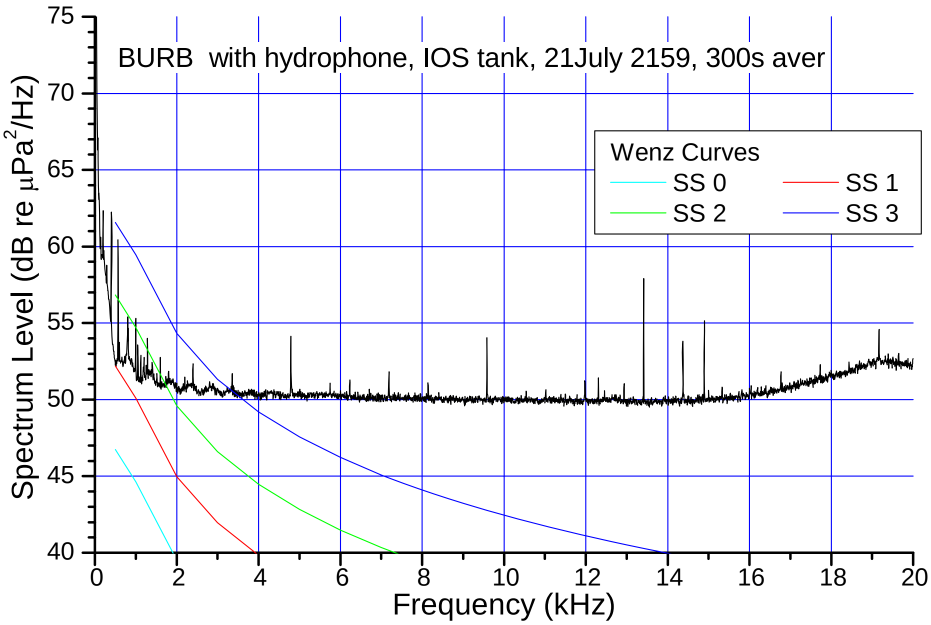

Figure 2-7 Internal noise spectra of BURB1 Chan.1 taken in the IOS test tank, 2159UT 21 July 2005. Comparison oceanic ambient noise curves for Beaufort sea-state 0 – 3 shown (from Wenz 1962).

Using this nominal calibration factor a lower measurement threshold can be calculated using the measured self-noise of the hydrophones, cables, amplifiers, and A/D converter electronics. This measurement was conducted using a BURBs unit, configured as for deployment, in an indoor test tank at IOS. In this situation with nearly zero acoustic input to the hydrophones, the hydrophone frequency response (described above) does not come into play. Measurements of this internal noise spectra were averaged over 5 minutes, using 8192-pt FFTs. In this configuration, the internal amplifier gains were set by the AGC to their maximum values (800x). The rms noise (with DC offset removed) in this channel was 639 counts, which given the gain and calibration factors mentioned above corresponds to a total SPL of approximately 104 dB re μPa. The typical time-averaged internal noise spectrum, corrected for the AGC and converted to dB re μPa^2/Hz, is shown in Figure 2-7. The figure shows an overall flat noise floor near 50 dB through the centre of the measurement band, rising slowly above 15 kHz due to thermal noise in the electronics then rolling off above 19 kHz due to the low-pass anti-aliasing filter. The rise below roughly 2 kHz is likely due to a combination of background electrical and acoustic noise in the tank, and may not represent true BURB internal noise levels. There are few narrow-band lines due to electrical oscillators (e.g. 60 Hz and harmonics) and background lab noise due to air-conditioners, etc. There is one relatively prominent internal noise line at 13.4 kHz, likely generated by oscillators on the CPU board. During early testing this was greatly reduced by adding an inductor to the hydrophone pre-amp power supply lines. For comparison, the standard ambient ocean noise curves for Beaufort sea-states 0 to 3 are shown. Clearly, the BURBs would only be able to resolve ambient noise spectra for sea-states 3 and above, with an upper limit of roughly 3 kHz at sea-state 3. At higher sea-states the ambient noise will be better resolved over an increasingly larger frequency range.

The pulse-per-second capability allows for precise measurement of the *actual* (as opposed to *nominal*) digitization rate. Figure 2-8 shows the pulse-per-second trigger occurrence (in digital samples) within successive 1-s data records. If the digitization rate was exactly 40,000 (as specified) the PPS trigger would occur at the same sample in successive records. The decreasing slope in PPS trigger occurrence corresponds to an actual sample rate of 39840 Hz (0.4% smaller). Some minor differences in this sample rate between the various BURBs units, and a minor sensitivity to temperature, should be expected.

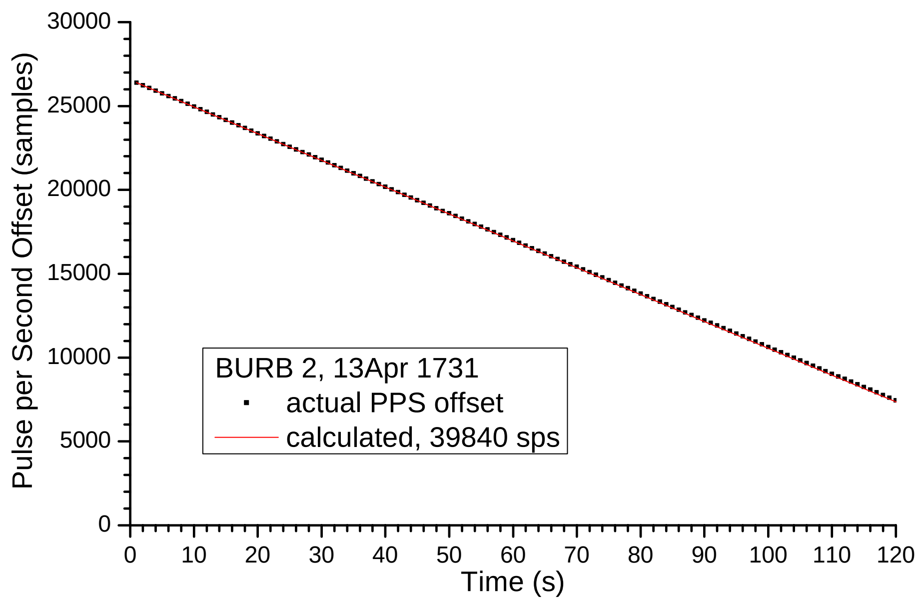

Figure 2-8 Time offset (in digital samples) of the GPS-based one-pulse-per-second trigger within successive 1-s duration data records, nominally sampled at 40,000 samples per second.

3. Example Sea-trial Results

3.1 Vessel Acoustic Signature Measurements:

A primary purpose for development of these buoys was measurement of the calibrated underwater acoustic signature of moving vessels. The field trials in March and April 2005 offered several opportunities to acquire such measurements on two different vessels, ranging from a small fishing troller to the 40-m Canadian Coast Guard Ship *Vector*. The fundamental measurement provided by the buoys is the sound pressure level (*SPL*) spectrum at each hydrophone depth. Note that vessel acoustic signatures are inherently broadband phenomena, and will be treated in this simple analysis as being omni-directional. What is desired is the vessel source level (*SL*) spectrum. The measured *SPL* is strongly dependent on the distance between the source vessel and the buoy, suffering a transmission loss which is to a first approximation given by a spherical spreading law and a frequency-dependent absorption term, i.e.

$$\mathrm{SPL}(f) = \mathrm{SL}(f) - 20*\log_{10}[r] - \alpha(f)*r \qquad \text{(in decibels)}$$

where r is the slant range between vessel and hydrophone and f is frequency. The absorption term is dependent on water properties (e.g. temperature, salinity, and depth), and is generally small at frequencies below 10 kHz. The absorption term can be calculated using relations found in Francois & Garrison (1982). In most deep-water measurement scenarios this simple model will be sufficient, however it should be noted that acoustic propagation effects, specifically reflections from the ocean surface and seabed and acoustic refraction, might complicate the transmission loss calculation at ranges greater than a few 100's of meters.

Figure 3-1 Photo of *RV Wicklow* passing close by a BURB at a speed of 7.8 knots, taken 24 March, 2005 in Patricia Bay, B.C.

The basic approach in measurement of the acoustic signature of the moving vessel is to have the vessel pass close by the BURBs during manoeuvres. Figure 3-1 shows a photo of the converted fishing troller *RV Wicklow* (10.6 m length) passing close by a BURB. *Wicklow* has a 3-bladed, 46-cm propeller. In the late-March 2005 tests only BURBs 1 and 2 were used, each having their hydrophones suspended at 5 and 15 m depth. By placing DGPS receivers on the source vessel, the vessel speed and heading can be measured and the slant range from the vessel to the hydrophone can be calculated using the BURB position. The slant range is calculated using a simple Pythagorean relation based on the horizontal distance and hydrophone depth. Figure 3-2 shows an example of this calculation for a straight-line pass at 7.8 knots by the *Wicklow*. Note that the ship to buoy separation shows the typical hyperbolic relation in time, with a closest-point-of-approach (*CPA*) of 12.8 m. Clearly the vessel passed to the North of the BURB2 on a nominally east-to-west track.

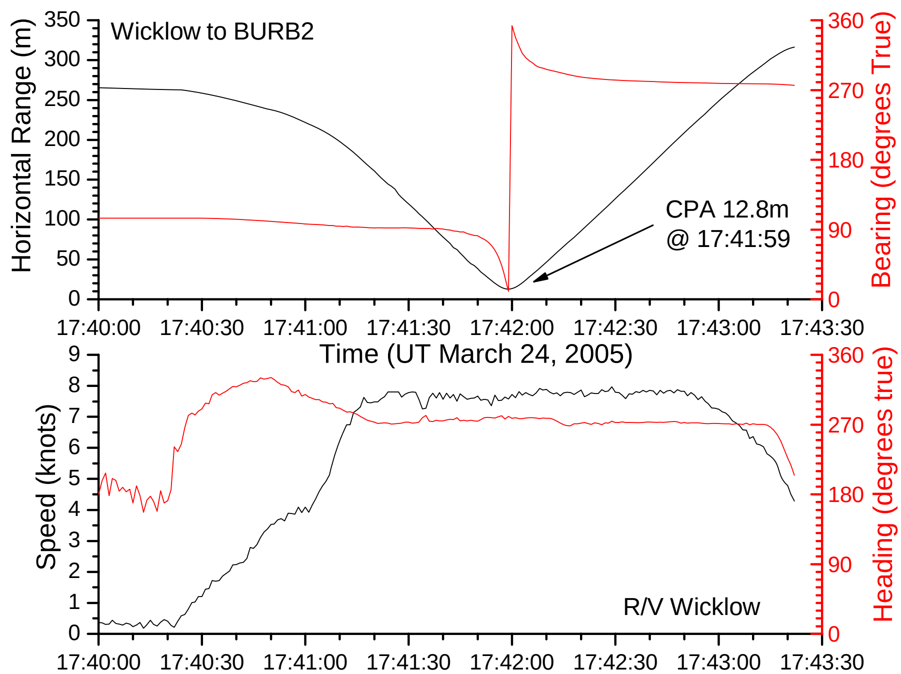

Figure 3-2 Vessel-to-hydrophone range and bearing (upper), and vessel speed and heading (lower) for a straight-line pass by the *RV Wicklow* past BURB 2, starting 1740UT 24 March, 2005 in Pat Bay, B.C.

By applying the above corrections for hydrophone response and target range to the measured spectra of the moving vessel, source level spectra can be calculated at a variety of ranges and incidence angles as the vessel passes. The most easily interpreted are the spectra measured near the *CPA*, as they are uncontaminated by Doppler shifting and correspond to the sound radiated near broadside aspect. Figure 3-3 shows a comparison of the raw and corrected SL spectra from two hydrophones of BURB 2. For these calculations a 8192-pt (205 ms) FFT was used, averaged over forty ensembles in 10 s. In the raw spectra, artifacts of the hydrophone response can be clearly seen; specifically the strong peak at 5 – 6 kHz and the accompanying drop-out at 8 – 10 kHz. Additionally, channel 2 appears to be dominated by an anomalously high noise level between 7 and 12 kHz. Since the *RV Wicklow* noise signature appeared to be dominated by low-frequencies (< 5 kHz) and the hydrophone response had a big drop-out above 6 kHz, it was appropriate to low-pass filter the vessel signature data with a

6 kHz corner frequency. The lower plot of Fig. 3-3 shows the estimated SL of the *Wicklow*, after low-pass filtering, correction for hydrophone frequency response, and correction for spherical spreading loss. The corrected SL spectra from the two hydrophones are in direct agreement with each other, showing a peak near 250 Hz with SL near 137 dB re $\mu Pa^2/Hz$, and a monotonic decrease at higher frequencies, varying as approximately frequency to the power -1.5. There is also a VLF peak at 5 - 10 Hz, presumably dominated by the propeller blade rate, but not well resolved with this FFT size and sampling rate. These features are all in agreement with expectations for boats of this size.

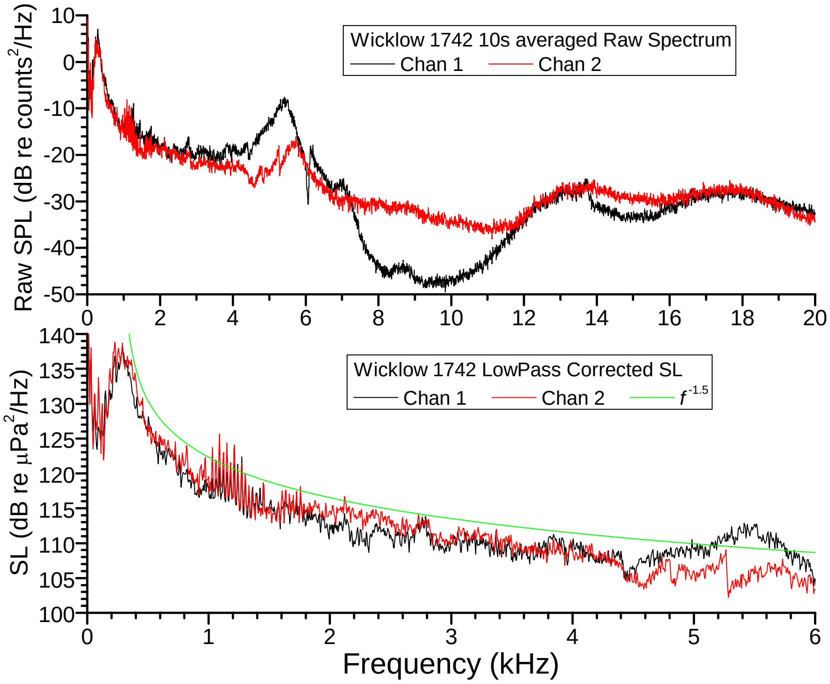

Figure 3-3 Measured raw (upper) and corrected (lower) source level spectra of the *RV Wicklow*, taken near CPA at 1742UT 24 March, 2005 in Pat Bay, B.C. Hydrophones 1 & 2 deployed at 5 and 15 m depth, respectively.

A similar set of measurements were performed with the larger *CCGS Vector* (see Figure 3-4), which performed a series of straight-line and turning manoeuvres in Saanich Inlet during a 3-day sea-trial in early April. The *Vector* has a single 3-bladed, 1.80 m diameter variable-pitch propeller, typically operating near 300 rpm at its maximum speed. Thus, propeller shaft and blade-rate lines near 5 - 15 Hz should be present in the acoustic signature. The *Vector* had two DGPS receivers, one near the bow and one at the forward edge of the aft deck. The bearing between these two GPS receivers gives the vessel orientation (possibly different from the heading over ground, particularly in turns). Also, any side-slip of the vessel during turns can be seen through the different trajectories of the bow and stern sensors. Similarly to the March 2005 trials, the hydrophones were suspended at 5 and 15 m depth. As before, the vessel speed, heading, and slant range from the vessel to the hydrophone can be calculated using the buoy position. Figure 3-5 shows an example of this calculation for a straight-line pass by the *Vector* at 11 knots. In this case the *CPA* to BURB1 was 58 m.

Figure 3-4 Photo of *CCGS Vector* approaching BURBs at a speed of 11 knots, during sea-trials on 13 April, 2005 in Saanich Inlet, B.C.

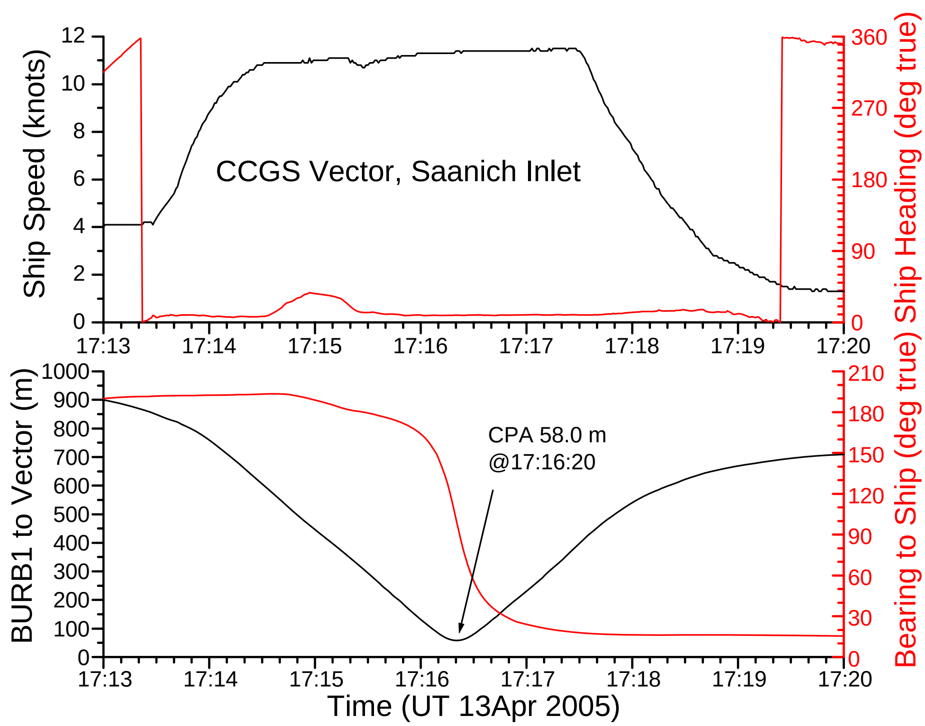

Figure 3-5: (upper): speed and heading over ground of the *CCGS Vector* during an 11-knot straight-line run on 13 April 2005 in Saanich Inlet, (lower): range and bearing from BURB1 to the ship bow.

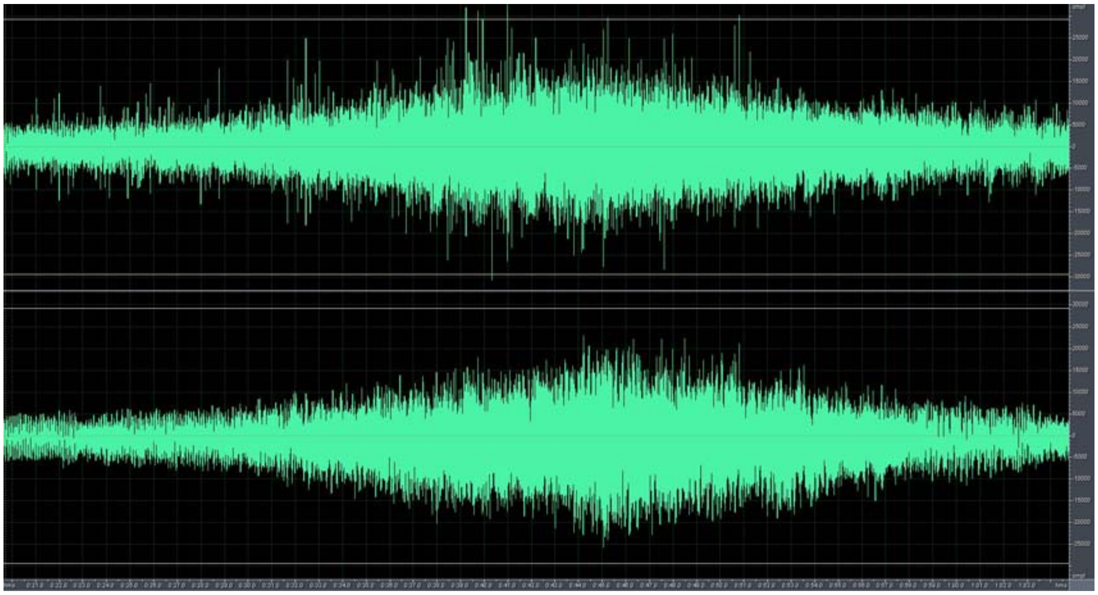

Figure 3-6 Measured raw acoustic time-series from BURB1 of the *CCGS Vector* near CPA, taken at 1716UT 13 April, 2005 in Saanich Inlet, B.C. Time-series cover a 44 s time interval. Upper hydrophone at 5 m depth, lower at 15 m.

The measured raw time-series as the Vector passed through CPA are shown in Figure 3-6. These data have been corrected for the internal BURB gains, then displayed using a commercial wave-file viewer (Cool Edit Pro v2.0). The overall measured amplitudes show an increase then decrease as the Vector passed through CPA, due primarily to the geometric transmission loss. It is interesting to note that the lower hydrophone showed a maximum amplitude somewhat later (roughly 5 s) than the upper hydrophone. This is speculated to be induced by propeller noise directionality effects.

A comparison of the raw and compensated SL spectra for this *Vector* pass is shown in Figure 3-7. As with the *Wicklow* data, artifacts of the non-flat hydrophone frequency response feature prominently in the raw spectra. The lower plot of Fig. 3-7 shows the estimated SL of the *Vector,* after low-pass filtering, correction for hydrophone frequency response, and correction for spherical spreading loss. There are a number of differences with the *Wicklow* results (Fig. 3-3). Firstly, the peak SL values for the *Vector* were approximately 10 dB higher than *Wicklow*, which was expected due to the greater speed and larger size of the vessel. For example, the corrected spectrum of channel 2 showed a peak near 150 Hz with SL near 149 dB (re $\mu Pa^2/Hz$ at 1 m). The corrected SL spectra of the two hydrophones were similar in overall shape, but at frequencies above 1 kHz the deeper hydrophone was 6 – 10 dB less than the upper. Additionally, there were a number of discrete noise lines (92, 200, 230, 270, 370, 580, and 730 Hz) in both corrected spectra, presumably due to various machinery harmonics. These machinery lines were largely absent in the *Wicklow* spectra. As expected, there was a strong VLF peak at 5 – 15 Hz due to propeller shaft and blade-rates. At frequencies above 1 kHz the corrected spectra show a relatively smooth decrease towards 5 kHz, with a broad peak centred at 1.5 kHz.

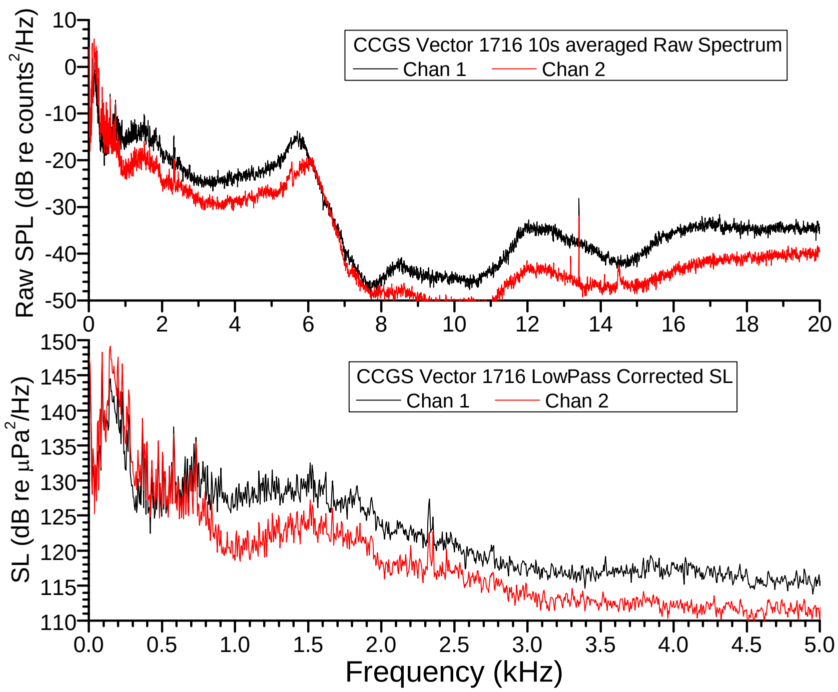

Figure 3-7 Measured raw (upper) and corrected (lower) source level spectra of the *CCGS Vector*, taken at 1716UT 13 April, 2005 in Saanich Inlet, B.C. Source time-series data shown in Fig. 3-6. Hydrophones 1 & 2 deployed at 5 and 15 m depth, respectively.

3.2 Acoustic Transmission Measurements:

A series of underwater acoustic transmission experiments were performed alongside the underwater radiated noise trials on the CCGS Vector in April 2005. These transmission experiments used a single broadband transmitter deployed from a Whaler, with the four BURBs as receivers. In these tests, a Medium-Frequency Multi-Mode Pipe Projector (MF-MMPP, see Fleming 2003) was used to transmit broadband (2 to 18 kHz) 10-ms duration pulses twice per second. The nominal acoustic source level was 180 dB (re µPa at 1 m) across this band. The transmit pulse waveform was pre-whitened to compensate for the frequency response of the MF-MMPP, described in Fawcett et al. (2005). The transmitter was deployed at 5 m depth from the Whaler, which was allowed to freely drift (engine off) near the BURBs. With GPS position data recorded at 1 s intervals on both the BURBs and the Whaler, the transmission geometry was known (see Figure 3-8). The basic technique was to drive the *Vector* at 11 to 12 knots in a straight line roughly perpendicular to the acoustic paths. The acoustic transmissions were started well before the passage of the *Vector*, allowing before and after comparisons. The acoustic transmissions were continued for approximately 12 minutes after the passage of the *Vector* to observe the effects of wake bubbles. In this 10-minute run a moderate SE wind pushed the Whaler and BURBs roughly 50 to 100 m NW.

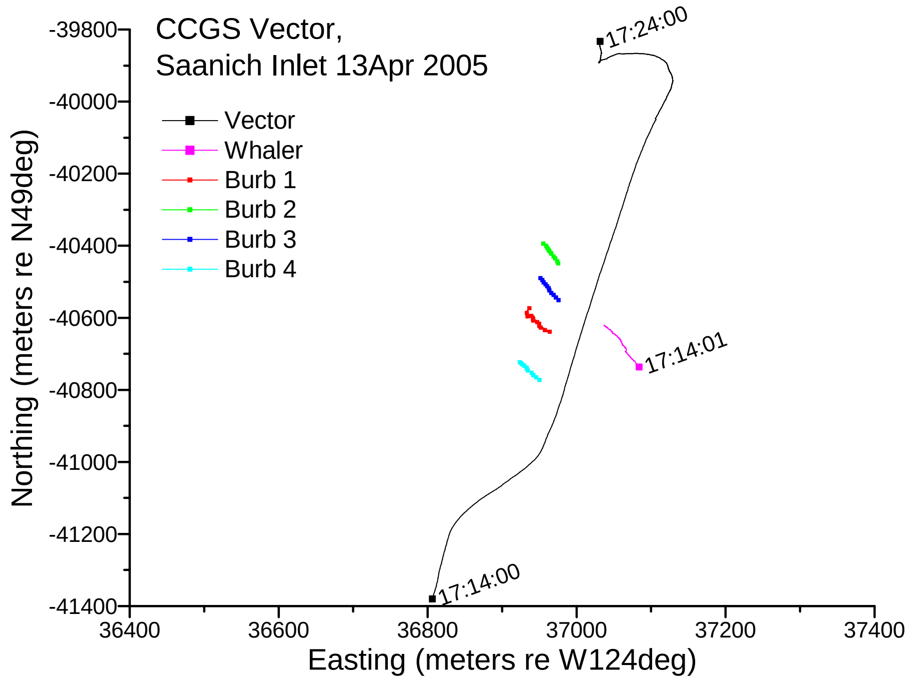

Figure 3-8: Position plot of BURBs, whaler (transmitter), and *CCGS Vector* in a northbound run at 11knots, 1714 to 1724UT 13April 2005 in Saanich Inlet, BC.

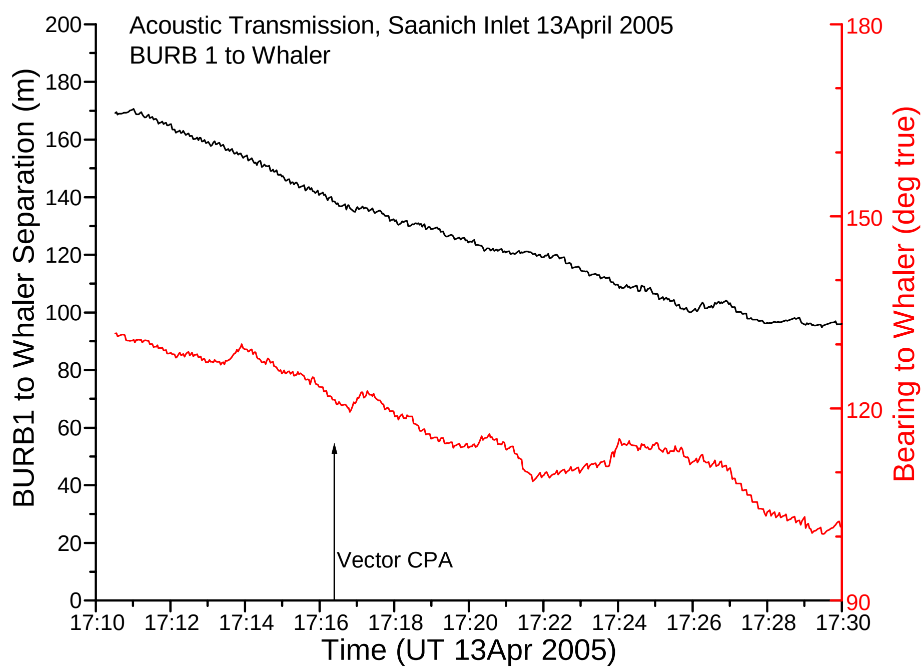

Figure 3-9: BURB1 to Whaler separation and bearing for acoustic transmission experiment 1710 to 1730UT 13April 2005 in Saanich Inlet

Since the Whaler drifted at a slightly higher rate than the BURBs, the transmitter-receiver separation generally decreased over this period, as shown in Figure 3-9. This separation distance can be used to calculate the non-bubble-induced Transmission Loss. In this run the geometric (spherical) spreading loss varied from 44.6 to 40.0 dB. At these short ranges the seawater absorption was generally negligible, being at most 0.48 dB (at 20 kHz) and less than 0.14 dB below 10 kHz. Variations in apparent TL, assuming a constant transmitter SL, from measurements before and after the ship passage can be attributed to the effects of bubbles in the ship's wake (detailed analyses of this kind will be reported separately).

The relatively broadband sampling of the BURBs allows for precise time-localization of pulses, as shown for example in Figure 3-10 with the a time-series of chirp pulse arrivals. In the lower plot the inter-pulse period of 0.5 s can be readily identified. In the close-up, the overall pulse length of 10 ms can be seen, along with the increasing frequency of the pulse as it ramps from 2 to 18 kHz. The pulse exhibits a drop-out in the middle, corresponding to frequencies in the range 7 to 10 kHz. The maximum amplitude section of the pulse near 0.724 s has frequency content near 4 to 6 kHz. These pulse characteristics are entirely consistent with the frequency response of the hydrophones, as described in Section 2.3.

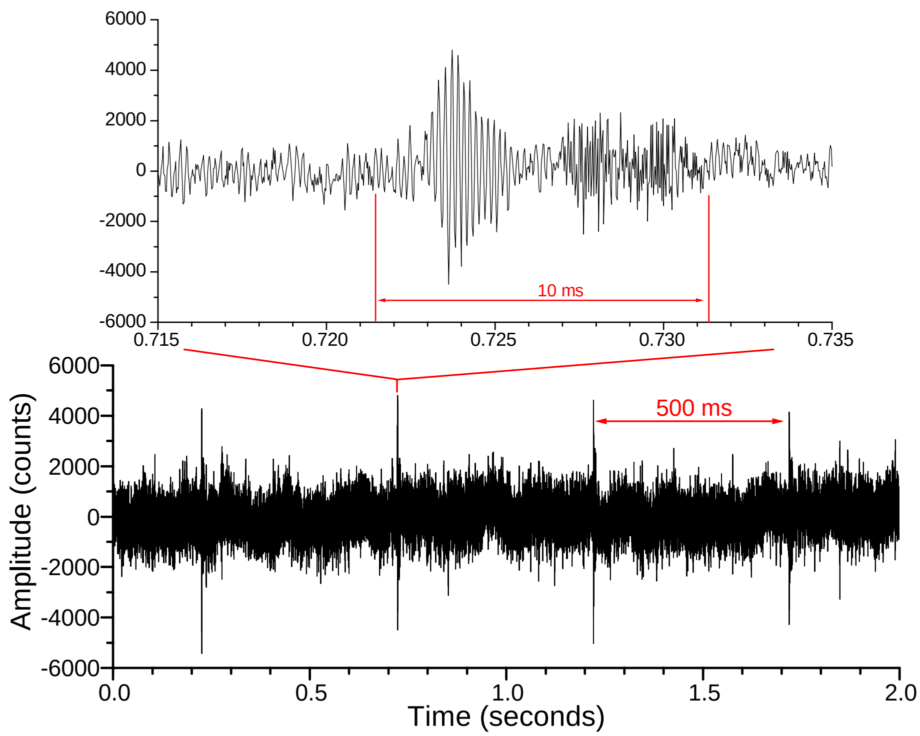

Figure 3-10: Raw amplitude time-series of 2-18 kHz by 10-ms chirp pulses received by BURB1, 5 m hydrophone approximately 3 minutes after the *Vector* CPA in the 11-knot run shown in Figs. 3-8 and 3-9. Upper plot shows a close-up of the pulse arriving near 0.72 s.

The inclusion of the PPS trigger in the data stream allows the possibility of measuring pulse time of arrival. To make this possible, the transmitter would have to be similarly synchronized to the GPS PPS trigger, which is feasible through use of the same DGPS receivers as incorporated in the BURBs. Unfortunately in these April 2005 sea-trials the transmitter system was free-running and not synchronized.

4. Discussions and Recommendations

This report documents the construction of and explores two intended applications of a new, multi-purpose underwater acoustic measurement system developed through a collaboration between Defence R&D Canada - Atlantic and the Institute of Ocean Sciences (Fisheries & Oceans Canada). Overall the collaboration was successful on a number of levels. IOS was able to deliver by April 2005 a set of four BURB units, advancing their technological capability in the process. It is anticipated that systems similar to the BURBs will be constructed and delivered to other Canadian government and university labs in the near future for marine mammal monitoring purposes. The DRDC Atlantic mine and torpedo defence group has now acquired a new broad-band underwater recording tool, intended primarily for use in the field experiments on wide-band pulse transmission. At the time of writing, several other groups at DRDC Atlantic have utilized BURBs in sea-trials for vessel underwater signature measurements and acoustic pulse transmission experiments. The system development was largely based around commercially available computer and hydrophone hardware, demonstrating the convenience and relatively low cost of following a commercial-off-the-shelf development approach. Additionally, the BURBs store digital data in a convenient, industry-standard WAV format, allowing use of readily available commercial software for replay and analysis.

Overall the BURBs have a capability for recording sound pressure levels (*SPL*) from 104 to 196 dB (re μPa) across a band from near DC to 20 kHz. This dynamic range includes both the A/D resolution (90 dB) and up to 58 dB of automatically adjustable gain. Internal noise levels set lower thresholds which have a modest frequency dependence, being higher at both the low and high ends. In this system a compromise in hydrophone performance was made to allow recording of higher *SPL* typical of acoustic transmission and vessel signature measurements. If recording of very low signal or ambient noise levels (*SPL* < 100 dB re μPa) is required, then higher levels of hydrophone sensitivity and/or pre-amplifier gain should be provided. Alternately, some impulsive acoustic sources (e.g. underwater detonations or pile driving operations) or high-power active sonar systems can exceed this maximum sound pressure level, even at great distances, resulting in overloading of the hydrophone pre-amplifiers and/or A/D clipping.

The incorporation of the pulse-per-second trigger into the data stream allows precise determination of time-of-arrival of acoustic pulses. This GPS-based capability removes the need for expensive and power-hungry high-precision internal clocks. Additionally, the multiple BURB and any separate transmitter systems can now be all synchronized to the same satellite-based PPS source, which is in turn synchronized to true UTC to better than 1 μs. Note that within these buoys the PPS trigger can only be localized in time to the nearest digital sample, or ±12.5μs (further note that GPS time is 13 s ahead of UTC due to the incorporation of leap-seconds in the latter).

The demonstration trials at IOS in March and April were able to successfully demonstrate measurement of moving vessel underwater acoustic signatures. In this report the underwater signatures of two vessels, a 10.6-m fishing vessel and the 40-m *CCGS Vector*, were reported at CPA of 12 and 60 m, respectively. For such trials it is a requirement to record the DGPS position of the target vessels at 1 s intervals, which is relatively easy to accomplish using a small GPS receiver with a laptop PC. The measured broad-band source level (*SL*) spectra of the fishing vessel *Wicklow* had a peak of 137 dB (re $\mu Pa^2/Hz$ at 1 m) at a frequency of 250 Hz, while the *Vector* showed a peak near 150 Hz with SL near 149 dB. Clearly, the frequency dependence of the radiated underwater noise can be easily determined, either directly through FFTs or using DEMON processing. Additionally, through examination of small time-segments as the vessel approaches and recedes from each BURB, the directionality of the radiated noise signature can be measured.

During the demonstration trials in April a number of acoustic transmission experiments were conducted. The pulses were broad-band chirps or sinc-pulses, with frequency content in the 2 to 18 kHz range. With a transmitter source level near 180 dB (re μPa at 1 m) the BURBs were able to record the acoustic transmissions at ranges in excess of 500 m with signal-to-noise ratios exceeding 20 dB. Clearly, some processing gain could be achieved through the use of matched-filter processing, extending the range of pulse reception. Match-filter processing also allows for precise determination of the pulse arrival time, potentially resolvable to ±1 digital sample (2.5 μs).

The BURBs need some mechanical improvements to facilitate convenient deployment and recovery at sea and provide better suspension for the hydrophones. Although the relatively calm conditions encountered in the March 2005 trials allowed deployment and recovery of the BURBs by hand from a small whaler, open ocean operations from a larger vessel will require more robust lifting points, and tracking aids such as a flag, a radar reflector, and a night-time strobe light. Additionally, during windy periods in April 2005 the lack of hydrophone suspension gear added some noise artifacts in the BURB data. This, in combination with the AGC set-point too large, generated an overly high background noise level. A compliant hydrophone suspension system, similar to that provided by sonobuoys, should be devised.

The acoustic calibration results (Fig. 2-6) showed a strong departure from the expected flat frequency-response. The variation in sensitivity from 5.5 to 7.5 kHz was more than 30 dB for all eight hydrophones. This accentuated signals in the 5.5 – 6.5 kHz range by more than 10 dB relative to the lower frequencies, and the sensitivity drop-out at 7 – 10 kHz produced low signal-to-noise properties in that band. Although variations of a few dB can be accommodated, such large frequency response deviations are considered unacceptable. Efforts are underway now to find replacement hydrophones. This may involve some modifications to the hydrophone conditioning cards, primarily in the provision of a different hydrophone pre-amp voltage (most COTS hydrophones require 12 VDC power).

Apart from bench-testing, a thorough examination of the performance the Wilcoxon TV-001 vector hydrophones has not yet been performed. It is intended that testing and calibration of these sensors will occur in early 2006 at the DRDC Atlantic Acoustic Calibration Barge.

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Appendix 1: BURBs Data File Format

The file structure is simple binary, with each file consisting of a 16-byte leader followed by multiple data records. Typical data file size is roughly 50 Mbytes. This data file structure is sufficiently similar to the .WAV format that most music replay programs can read it (the GPS string and gain values will thus be interpreted as data, yielding a spike at 1 s intervals).

Data File Leader:

```
int*4   Burb        ! buoy number (1 through 4)
int*4   Chans       ! number of channels (2 for hydrophones, 4 for TV-001)
int*4   BufLen      ! data buffer length (total number of samples)
int*4   SampFreq    ! A/D conversion rate per channel
```

Typical values (in hydrophone configuration) for the BufLen and SampFreq are 88004 and 44000, respectively, which implies that each data record is almost exactly 1 s duration.

Repeating Data Record:

```
char    GPSstring[72]       ! NMEA GPRMC message (see Appendix 2)
int*2   databuf[BufLen]     ! data buffer
```

Each channel has an automatically adjusted gain, being the product of two gain stages. The first four elements of databuf[] contain these gain values:

databuf[0] = Chan 1 Gain 1
databuf[1] = Chan 1 Gain 2
databuf[2] = Chan 2 Gain 1
databuf[3] = Chan 2 Gain 2

Gain 1 values (0 through 5): 1.0, 2.0, 5.0, 10.0, 20.0, 50.0
Gain 2 values (0 through 15): 1.0, 2.0, 3.0,…, 16.0

Then databuf[4] and higher contain the signed 16-bit integer (±32768) data samples, alternating left and right channels.

The GPS-derived pulse-per-second (PPS) trigger is embedded in the raw data stream as the least-significant data bit, i.e. LSB = 1 (in both channels) on trigger event, otherwise LSB = 0. The PPS trigger is 20 ms (approximately 800 samples) in length.

Alternate Format for the Wilcoxon TV-001 sensor:

When configured and recording this 4-channel sensor, the overall data file format is similar to the above structure, with the following adaptations:

a. There are now a total of 8 gain settings, e.g. with databuf[4,5] containing the two gain values for Chan. 3, and databuf[6,7] containing the gains for Chan. 4.

b. The actual channel data is written sequentially, i.e. repeating cycles of chan 1, 2, 3, 4, each a 16-bit signed integer at the sampling rate defined in the Leader.

c. Channel assignments: Chan 1 = pressure, Chan 2 = x-acceleration, Chan 3 = y-acceleration, Chan 4 = z-acceleration.

Appendix 2: GPRMC format

The output of the Differential GPS system is embedded in the hydrophone data files as a 72-character string in the header of each data record. The $GPRMC message, an NMEA standard, was chosen because it contains all the essential information, e.g. time, date, latitude, longitude, speed, and heading.

Example:
$GPRMC,190553,A,4839.0476,N,12326.9957,W,000.0,144.6,170305,018.7,E*6E

Field	Description	Symbol/precision
1	Log header	$GPRMC
2	Time in UTC	hhmmss
3	Position status, A = valid, V = invalid	A
4	Latitude, degrees-minutes-decimal minutes	DDmm.mmmm
5	Latitude direction (N = north, S = south)	N
6	Longitude, degrees-minutes-decimal minutes	DDDmm.mmmm
7	Longitude direction (W = west, E = East)	W
8	Speed over ground, knots	xxx.x
9	Heading made good, degrees true	xxx.x
10	Date UTC	ddmmyy
11	Magnetic variation (deg)	xxx.x
12	Magnetic variation direction (E or W)	E
13	Checksum	*HH
14	Sentence terminator	[CR][LF]

Appendix 3: Summary of hydrophone assignments and calibration coefficients

The hydrophones used in BURBs are model CR-100 units manufactured by Burns Electronics Pty. of Salamander Bay, NSW, Australia (www.burnselectronics.com.au). These 8 hydrophones were specially modified for a +20 dB preamplifier gain operating on 6.8 VDC. The design hydrophone sensitivity was -185 dB re 1 V/μPa. The nominal pass-band quoted by the manufacturer is 7 Hz to 100 kHz. The hydrophones are omni-directional perpendicular to their long-axis (i.e. horizontal), with a 270° beam-width (to –3 dB) in the vertical plane. The hydrophones are 140 mm in length by 19 mm diameter, built around a stainless steel pressure case rated for 400 m depth.

BURB	Channel	Serial Number	Bare Hydrophone Response @ 1 kHz (dB re V/μPa)	Conversion Factor (dB re μPa/count)
1	1	004-20	-186.94	107.74
	2	006-20	-186.03	106.83
2	1	005-20	-188.12	108.92
	2	010-20	-187.28	108.08
3	1	003-20	-186.84	107.64
	2	009-20	-186.41	107.21
4	1	001-20	-187.17	107.97
	2	008-20	-186.50	107.30

The Conversion Factor is determined by matching hydrophone-only calibrations with full BURB electronic measurements at 1 kHz. The overall frequency response of the system is then contained in a normalized hydrophone response curve for each hydrophone.

Calibrations of the Wilcoxon TV-001 sensors have not yet been performed.

Appendix 4: Operating instructions and helpful hints

During storage the BURB electronics is normally connected to its internal battery pack, but is in a very low power mode waiting for a signal from the ***ON*** magnetic switch mounted on the underside of its top end cap. This switch is enabled by passing a magnet over it.

When the ***ON*** command has been given the BURB electronics is powered-up and its internal PC boots up into Windows 2000. This will take roughly 2 minutes. During the boot phase, the LED mounted in the GPS antenna glows dimly. Once the boot-up is complete, the LOGDATA.EXE program automatically starts. The GPS receiver should have locked-on to a position by this time (provided the antenna has an unobstructed view of the sky). Operation of this program is indicated by rapid flashing of the GPS LED (IDLE mode).

If the ***ON*** switch is set once again by passing a magnet over it, the program will begin data recording (LOGGING mode). Logging mode is indicated by the LED flashing once every two seconds. Passing the magnet over the ***ON*** switch again will toggle the program to return to IDLE mode. Further magnet passes will act as a toggle between LOGGING and IDLE modes. If the system appears unresponsive to the magnetic switches at any time, there is a reset switch available on the external interface box. This will reset the onboard PC, causing a reboot.

The operation of the BURB may also be observed and modified over an Ethernet connection, using the external interface box and a separate computer. The Ethernet connection can be either a crossover CAT-5 cable, or a regular CAT-5 cable connecting to a local area network. It is advisable that the 2^{nd} PC run Windows NT/2000/XP. The freeware program, Ultra VNC Viewer v1.0.0- RC 20, should be running on the monitoring PC, and will allow one to control the BURB by viewing its desktop on the monitoring PC. When starting up VNC Viewer, the BURB IP addresses should be used as the server name, and the password required is "123".

The BURB incorporates automatic gain control (AGC) circuits and software to enhance the system's dynamic range. This gain level used is recorded within the data files at 1 s intervals (see Appendix 1). The gain can vary from x1 to x800.

Once the user is satisfied that the program is recording data, the external interface cable should be removed from the XSK-12-BCL connector on the BURB end cap, and the connector should have the dummy cap installed. The instrument can now be deployed.

Each BURB has sufficient battery capacity for more than 36 hours of continuous operation. Data recording capacity is many times the battery lifetime, so that data from previous deployments need not be removed prior to use.

Once the BURB has been recovered, the LED on the GPS disc should be observed. Check that it is still flashing every two seconds, indicating LOGGING mode. To return to IDLE mode, pass the magnet over the ***ON*** switch. If the LED is not flashing on recovery, the BURB has probably shut itself down or experienced some kind of malfunction. The logging program will normally shutdown only under two conditions:

1. A magnet is passed over the ***OFF*** magnetic switch when the system is in IDLE mode (this is the preferred method for shutdown). The LED will stop flashing altogether, the internal PC performs an orderly shutdown, and the power will be switched off roughly 30 seconds later.

2. The program detects that the battery voltage has dropped to a low enough level that further operation would be harmful to batteries or to the system (LOWBATTERY mode). Again an orderly shutdown and power-down occurs.

To retrieve the data, reconnect the external interface box and hook the BURB up to its battery charger. One can now transfer raw data files from E:\DATA back to another PC via the ethernet cable. If one is using VNC Viewer, it is convenient to use the File Transfer facility (fourth icon from the right at the top of the program window) to perform this task. Data transfer may be somewhat faster by using VNC Viewer to *Stop* the LOGDATA program through it's window that appears on the BURB desktop (note that this pauses the program, but does not exit. When data transfer is complete, press the *Resume* button in the LOGDATA window).

If one is using a computer without VNC Viewer installed, one can simply locate the BURB on the network using Network Neighbourhood. A box may appear asking for username and password. Enter "administrator" for username and leave the password field blank before hitting the "enter" key. Then copy files needed from E:\DATA on the BURB.

BURB IP addresses:	BURB 1	192.168. 1. 61
	BURB 2	192.168. 1. 62
	BURB 3	192.168. 1. 63
	BURB 4	192.168. 1. 64

The BURB Logdata program supports two different instrumentation configurations: a pair of Burns Electronics CR-100 hydrophones, or a single Wilcoxon TV-001 Miniature Vector Sensor. Presently, the two CR-100s are sampled at 40 kilosamples/sec each, while the TV-001's four channels are each sampled at 20 kilosamples/sec. Which instrument is being recorded is determined by the CONFIG.CFG file, found in D:\config\ on the internal hard drive. This file may be modified using a text editor through the VNC Viewer; an example file appears below (Figure A4.1). Anything following the '%' symbol to the end of that line are comments. For two hydrophone mode, set the number of channels to 2. For a single directional TV001 hydrophone set number of channels to 4. AGC parameters should be modified with extreme care (See Section 1.2 for a description of the AGC parameters).

```
% Configuration file for BURB logging program
% Updated May 26, 2005
% Updated by S. Vagle
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
Number of channels: 2 %2=Two hydrop., 4=TV-001 Directional Hydrop.
AGC Filter attack coefficient:  0.05    % Between 0 and 1
AGC Filter decay coefficient:   0.99999       % Between 0 and 1
AGC Counts level to aim for:    10000         % Between 0 and 32000
```

Figure A4.1: Example of the BURB configuration file D:\CONFIG\CONFIG.CFG

The data logging program for each BURB is called LOGDATA.EXE and is located in a directory D:\BURB\LOG\DEBUG\ on each unit. All data will be written to the directory E:\DATA\. The configuration file (CONFIG.CFG) resides in a directory D:\CONFIG\. Note that there is considerable excess in recording capacity relative to the operating duration (roughly 36 hours) which is limited by the batteries. Thus data need not be removed after each deployment. BURBs generate data at the rate of roughly 10 MB per minute, or roughly one CD-Rom every hour. The 70 Gbyte data storage drive thus has a total data recording capacity near 120 hours.

During sea-trials in the fall of 2005 some cross-talk was observed between the BURBs and VHF radio direction-finding (RDF) beacons mounted on the top frame. This cross-talk generated distinct a 1 s tone and harmonics at uniform intervals (typically 5 to 20 s depending on the beacon), usually inducing a change in AGC settings. This cross-talk is most obvious when there is a low level of background acoustic noise, such that the AGC would normally be set relatively high.

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(U) This report documents the design and features of a new, four−element broad−band underwater recording buoy system. These buoys, named the Broad−band Underwater Recording Buoys (BURBs), were built to facilitate medium−frequency underwater acoustic transmission experiments and for measurement of moving vessel acoustic signatures. Each BURB supports two wide−band hydrophones, digitized with 16−bit resolution at 40,000 samples per second each, and recorded onto internal hard−drive. Each BURB records its differential GPS position at 1 s intervals. Total operational duration is in excess of 36 hours of continuous operation. In an alternate configuration, each BURB can acquire four−channel data from a new 3−axis acoustic intensity sensor. This report presents details on the BURB design, construction, acoustic calibration, and operation. Example results from acceptance sea−trials conducted in March and April 2005 are presented.

(U) Le présent rapport documente la conception et les caractéristiques d’un nouveau système de bouées d’enregistrement sous−marin large bande à quatre éléments. Ces bouées, appelées « bouées d’enregistrement sous−marin large bande » (Broad−band Underwater Recording Buoys – BURB), ont été construites pour faciliter les expériences de transmission acoustique sous−marine et la mesure des signatures acoustiques de navires en mouvement. Chaque BURB est associée à deux hydrophones large bande dont les signaux sont numérisés à une résolution de 16 bits avec 40 000 échantillons par seconde et sont enregistrés sur un disque dur interne. Chaque BURB enregistre sa position GPS différentielle à des intervalles de 1 s. La durée totale d’exploitation continue dépasse les 36 heures. Dans une autre configuration, chaque BURB peut acquérir des données sur quatre canaux transmises par un nouveau capteur d’intensité acoustique trois axes. Nous présentons ici des détails touchant la conception, la construction, l’étalonnage acoustique et le fonctionnement des BURB ainsi que des exemples de résultats des épreuves de fonctionnement en mer menées en mars et avril 2005.

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(U) underwater acoustics; hydrophones; vessel acoustic signatures

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